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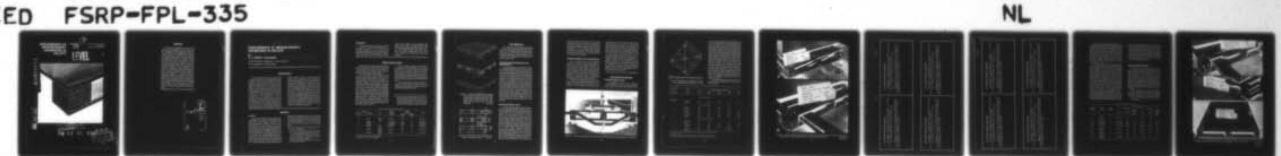

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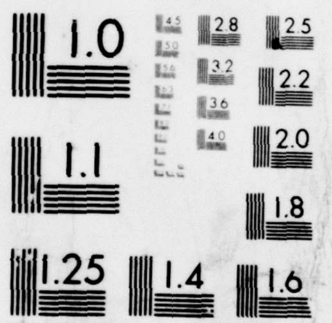

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PERFORMANCE OF MEDIUM-DENSITY HARDBOARD IN PALLETS

RESEARCH PAPER FPL 335

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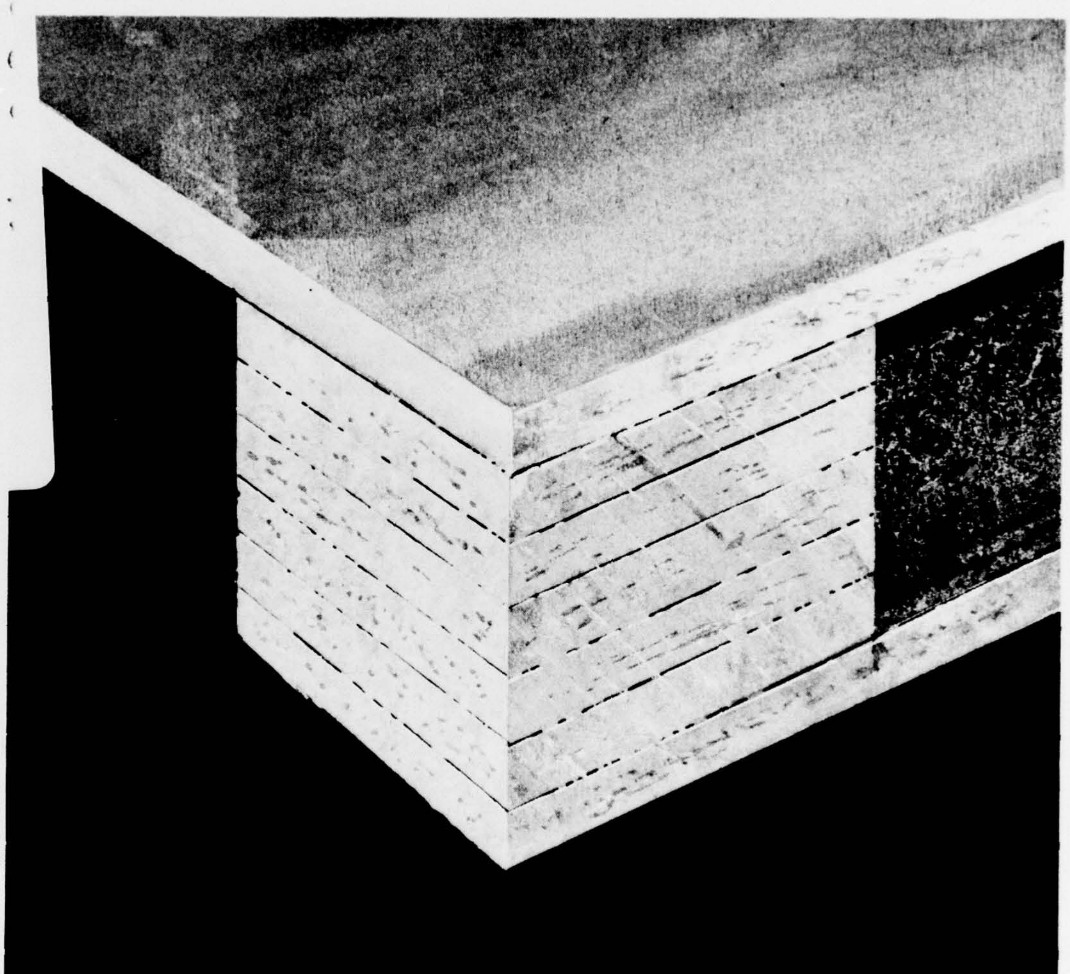

Abstract

This report compares the use of medium-density hardboard with red oak lumber for reusable shipping pallet construction. If practicable, use of hardboard for this purpose would help to establish the utilization of low-grade wood waste for present and future pallet construction. The work indicated that for 9-block, 4-way entry pallets, a 1-inch top deck thickness is needed to achieve comparable performance with lumber pallets. Also, pallets of this style and having 1-inch-thick hardboard decks appear to be equal to, or better than, all-lumber pallets for use in mechanical handling and automatic palletizing systems—i.e., where pallet dimensional stability is necessary for smooth operation of the system. This is the first of three studies being conducted to determine the most effective and efficient hardboard pallet design. The results should be especially relevant to anyone manufacturing, procuring, or using wood pallets at the present time.

(6) (9) Research paper,

PERFORMANCE OF MEDIUM-DENSITY HARDBOARD IN PALLETS

By
(10) **R. K. STERN, *Technologist*** (14) FSRP-FPL-335

Forest Products Laboratory,[1] Forest Service
U.S. Department of Agriculture (11) 1979 (12) 15

Introduction

A more complete use of low-grade wood in whole trees can be achieved by greater manufacture and use of hardboard. By this method, a larger portion of the tree can be reduced to fibers and reconstructed as hardboard. This permits use of limbs and misshapen or small lengths of wood usually left at the logging site, as well as scrap lumber produced by sawing for grade. One potentially large use for such hardboard is in pallet construction.[2] This publication is one of several FPL reports dealing with the basic engineering characteristics and performance of hardboard in use as shipping pallet component material. One important aspect of this work is that experimental hardboard pallet performance was compared to that of lumber pallets of similar design. Red oak pallets were selected as the comparative standard (controls) for this work because of their general availability, nominal cost, and frequent use. Previously, limited work had been reported for pallets of the same design, but the hardboard was limited to a ¾-inch thickness for 48- by 40-inch and 40- by 48-inch 9-block, 4-way entry pallets (*2*).[3] Basic mechanical strength properties of similar experimental hardboard panels were reported in (*3*) and (*7*). The work described herein was conducted to determine the effect upon pallet performance caused by replacing various lumber components with medium density hardboard of different thickness.

Material

Lumber

A sufficient supply of green lumber was obtained at a local sawmill and stored underwater until used for pallet construction. The rough boards were nominal 1- and 2-inch No. 3A common red oak material. Just before manufacture as pallets, the material was surfaced, trimmed for compliance with the minimum requirements for NWPCA Grade A pallet parts (*4*), and the resulting pieces were cut to the proper size for subsequent pallet construction. At this time the lumber parts were randomized, covered with 6-mil polyethylene film to retain moisture, and stored briefly at 36° F and 82 percent relative humidity until fabrication as pallets. A check of the various boards just before assembly indicated that the moisture content of all lumber parts was well above 30 percent—i.e., the fiber saturation point where checking and shrinkage begin.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Lumber used for this purpose during 1977 (the latest year for which statistics are available) was reported by the National Wooden Pallet and Container Association to be greater than 15 percent of the U.S. Department of Commerce estimate of 37.5 billion board feet harvested in the USA in 1977.

[3] Underlined numbers in parentheses refer to literature cited at the end of report.

141 700

Hardboard

At the Laboratory's request, 44 pounds per cubic foot, urea bonded hardboard in a sufficient quantity of ½-, ¾-, and 1-inch thickness panels were commercially made. A brief check of the fibrous content of the hardboard was made with a compound microscope (100 to 500x), and the material was boiled to free fibers for identification. The fiber composition observed by random selection was principally beech, basswood, birch, oak, and maple. Occasionally, fibers from cherry, spruce, and white pine were also observed.

Pallet Construction

Seventy 9-block type, 4-way entry 48- by 40-inch single deck pallets were constructed for evaluation in this work. Specifically, 10 pallets were made for each of the combinations of variables described in table 1.

As a first step in construction of the lumber control pallets (figs. 1A and 2A), the stringer boards were nailed and clinched to the undersides of the top deckboards with fivepenny cement coated nails. Next, the resulting assembly was nailed to the blocks with 3½- by 0.150-inch helically threaded pallet nails. Finally, the bottom deckboards were nailed to the blocks with standard 2½- by 0.120-inch pallet nails. The average MIBANT (bending angle test) value (5) for the latter nail was 17, while the corresponding average value for the former was 7.[4] All nails were driven in a staggered fashion to minimize post splitting, such as might occur had they been driven into opposite sides of the posts at similar locations.

The two pallet designs with hardboard components in this work (figs. 1 and 2, B and C) used 2½- by 0.120-inch helically threaded pallet nails throughout. However, the same nailing pattern was used over all joints involving blocks throughout the study. No fivepenny nails were used with hardboard pallets because stringer boards were not employed (fig. 1).

Following assembly, all pallets were exposed to uncontrolled, ambient indoor atmospheric conditions for at least one month (during August) before testing.

[4] *Note:* Presently, the National Wooden Pallet and Container Association recommends a minimum MIBANT nail hardness value of 13-28. Therefore, use of a "very tough hardened steel" nail (as nails having a MIBANT hardness value of "7" are being classified) for this portion of pallet assembly was conservative.

Table 1.—*Construction variable combinations*[1]

Top deck		Blocks	Bottom deckboard thickness	Weight when tested		Design
Thickness	Composition			Range	Average	
In.			*In.*	*Lbs*	*Lbs*	
¾	Lumber	Red oak (solid)	¾ (red oak)	54-59	57	Fed. Spec. (9)
½	Hardboard	[2]	½ (hardboard)	49-54	51	Fed. Spec. (8)
¾	Hardboard	[2]	¾ (hardboard)	65-68	66	Fed. Spec. (8)
1	Hardboard	[2]	1 (hardboard)	81-84	83	Fed. Spec. (8)
½	Hardboard	Red oak (solid)	¾ (red oak)	47-51	49	Fed. Spec. (8)
¾	Hardboard	Red oak (solid)	¾ (red oak)	59-63	60	Fed. Spec. (8)
1	Hardboard	Red oak (solid)	¾ (red oak)	72-73	72	Fed. Spec. (8)

[1] Five pallets were tested for each combination.
[2] Laminated from remnant ¾-in. hardboard.

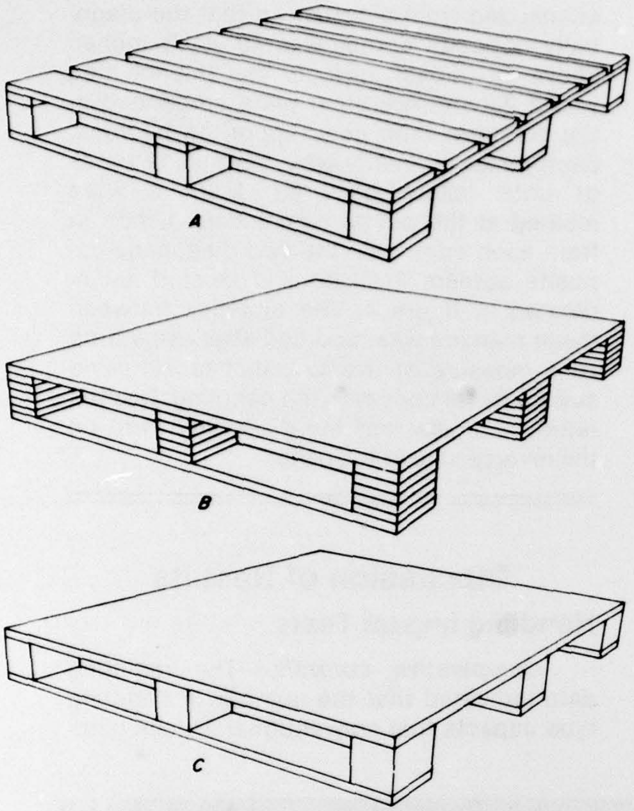

Figure 1.—Three basic pallet types included in this work: A. lumber control pallet; B. 9-block pallet made entirely from hardboard; and C. 9-block pallet with hardboard decks and solid red oak parts, otherwise. (M 146 225)

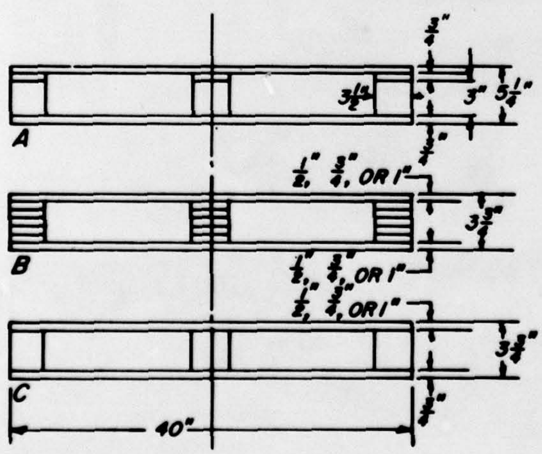

Figure 2.—Front views and dimensions of pallets indicated in figure 1. (M 146 804)

Test Methods

Two equal sets of 35 pallets were tested to failure. The first set was tested directly to failure by the pallet handling impact resistance test of (6). The other matching set of 35 pallets was given nondestructive bending stiffness tests, followed by destructive diagonal rigidity tests.

Handling Impact Resistance Test (Destructive)

This test basically consisted of impacting the pallet with the forks of a forklift truck as in normal usage. The test procedure was the same as that described in Part II of (6), except that the test was discontinued after 550 impacts if the pallet was still serviceable. Whereas the referenced procedure involved impacts on a single end of each pallet, the tests discussed herein involved impacts on both (opposite) ends of their 48-inch lengths. Handling impact testing of any particular end involved a series of tests by either a conventional forklift truck or one equipped with an impact panel. Equal numbers of pallet ends were tested by each technique. Forklift truck impact speed customarily ranged from 1.98-2.02 miles per hour, but readings as low as 1.86 and as high as 2.06 miles per hour were observed.

Bending Stiffness Tests

As indicated, 35 pallets were given nondestructive bending stiffness tests. Each pallet was loaded by a universal testing machine moving at 0.1 inch per minute at the quarter points of 36- and 44-inch spans in accordance with (7), except that three rather than two loading cycles were averaged. Deflection readings were made with a pair of metal yokes suspended from the midpoints of the outer two blocks at opposite ends of the test pallet. The deflection of the movable element of an LVDT (linear variable differential transformer) coupled to the yoke on each end sensed the pallet deflection, and the resulting voltages were fed into an x-y recorder. Pairs of load-deflection graphs resulted, and from these the average stiffness was calculated for the linear portion of the curves. A

typical test setup is shown in figure 3. Each bending test was conducted to a stage well below the yield point in order to minimize the possibility of pallet failure at this time. Upon completion of the nondestructive loading described, each pallet was rotated 90 degrees, and a second set of three successive loading cycles was applied.

Diagonal Rigidity Tests (Destructive)

Use of excessively racked (distorted) pallets can produce costly time delays, if they are used in an automatic palletizer of a continuous conveyor system. Similar jamming problems result when they are used with a computer controlled automated storage system. Therefore, as a part of the overall evaluation, drop tests were conducted to compare the diagonal rigidity of hardboard pallets with that of the red oak controls.

Following nondestructive bending stiffness testing, the same 35 pallets were subjected to diagonal rigidity testing, as prescribed in (*1*). In essence, each pallet was suspended from a corner so that the diagonally opposite corner was 40 ± 1/8 inches above an impact surface. The impact area was a 2-inch-thick steel plate embedded in the concrete floor and supporting bedrock. Each pallet ordinarily was dropped 12 times or until failure occurred. Markers were located at the points common to 1 inch in from each edge near the two diagonally opposite corners involved and labeled as indicated in figure 4. The distance between these markers was recorded after every drop as a measure of overall pallet racking and suitability for conveyorized handling. Dashed letters indicate that the diagonals were on the reverse side of the pallet.

Discussion of Results

Handling Impact Tests

Comparative controls.—The resulting data indicated that the number of handling type impacts that conventional 9-block hard-

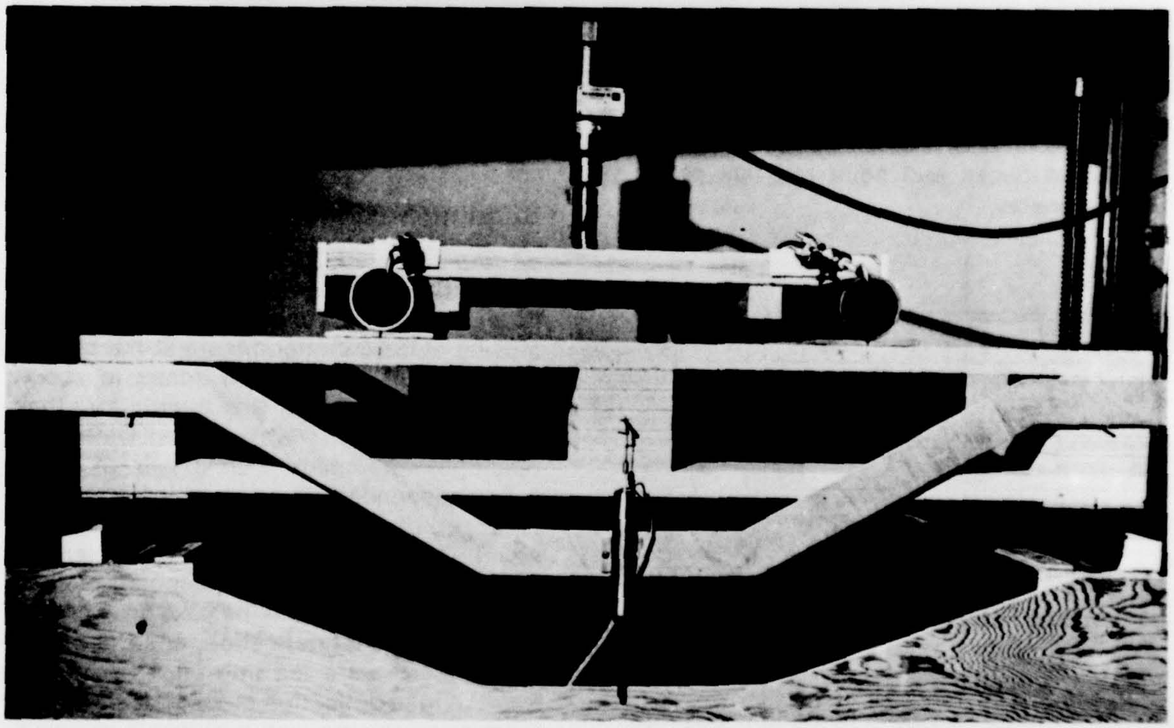

Figure 3.—Loading arrangement for all-hardboard pallet during bending stiffness test. (M 145 865-11)

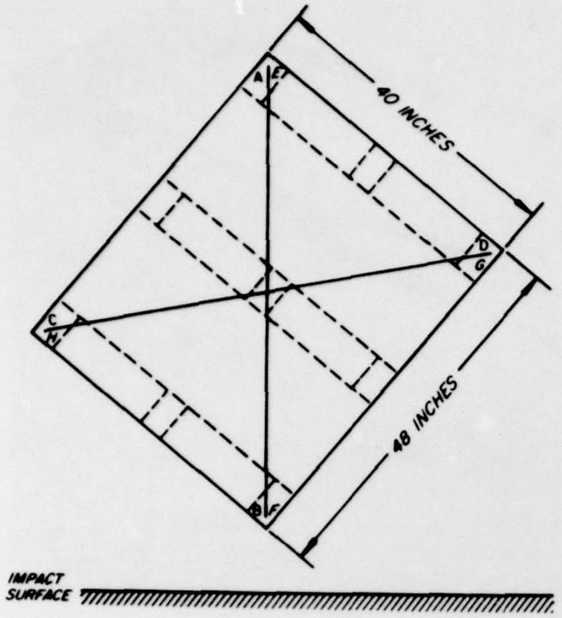

Figure 4.—Orientation of diagonals of pallet during diagonal rigidity testing. (M 146 805)

wood lumber pallets withstood ranged from 2 to 17 and averaged 9. This performance was similar to that of red oak partial 4-way entry returnable pallets under similar testing conditions (*6*). In sharp contrast, similar tests on the opposite ends of the same pallets by the forklift truck equipped with an impact panel produced only minor damage by 550 impacts. Typical pallet conditions after testing are shown in figure 5, wherein *A* illustrates the pallet end condition after testing with a conventional forklift truck and *B* depicts the typical condition of a previously untested end after similar testing, except that the location and nature of applied shock pulses to the pallet were altered by use of an impact panel. Based on these observations, an estimate for acceptable handling impact performance of pallets made either partly or entirely of hardboard components could be made at this time.

A complete quantitative summary of the test results for all pallet tests of this type is given in table 2.

Table 2.—*Results of handling impact resistance tests of individual pallets tested on opposite ends by a conventional or modified forklift truck*

Top deckboard or panel thickness	Forklift truck condition	Number of impacts[1] and sequence				
		Pallet No. 1	Pallet No. 2	Pallet No. 3	Pallet No. 4	Pallet No. 5
In						
		Lumber Pallet Controls				
Nominal 1 inch lumber[2]	Conventional	2*	6	14*	17	7*
	Modified	550	550*	550	550*	550
		All Hardboard Pallets				
½	Conventional	104*	1[3]	469	127*	4
	Modified	550	335*	550*	44	77*
¾	Conventional	378*	466	75*	205	178*
	Modified	550	550*	550	550*	550
1	Conventional	550	550*	550	550*	550
	Modified	550*	550	550*	550	550*
		Pallets with Hardboard Decks				
½	Conventional	97*	1[3]	8*	1[3]	29*
	Modified	28	41*	3	25*	6
¾	Conventional	272	359*	201	64*	89
	Modified	550*	550	550*	550	550
1	Conventional	550*	550		(Cancelled)	
	Modified	550	550*			

[1] Until pallets had failed, were considered to require repair, or had received 550 impacts.
[2] ¾-in. green red oak.
[3] Pallet deck essentially had failed because of the first loading on the opposite end.
* Indicates the condition, conventional or modified, which was tested first; then the other.

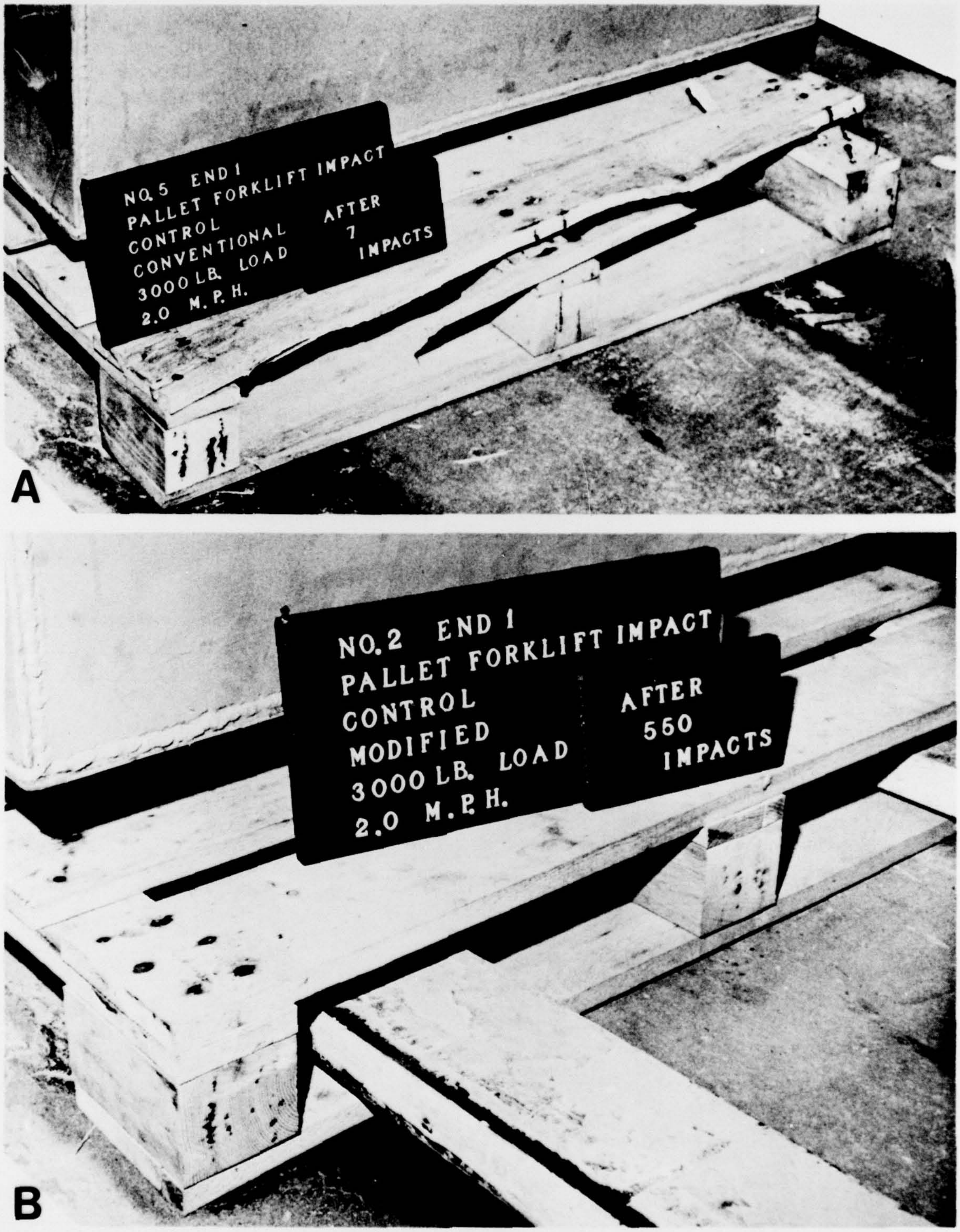

Figure 5.—Typical lumber pallet damage: A. after 7-conventional impacts and B. after 550 impacts varying only in that an impact panel was used by the forklift truck.

(M 145 507-13)
(M 145 508-1)

U.S. Forest Products Laboratory.

Performance of Medium-Density Hardboard in Pallets, by R. K. Stern. Madison, Wis., FPL 1979.
13 p. (USDA For. Serv. Res. Pap. FPL 335).

Compares the use of medium-density hardboard with red oak lumber in reusable shipping pallets. Explains test methods and results of tests.

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Pallets with hardboard components.—It became obvious as the research progressed that generally, because of damage to the top panel (the principal structural element of the pallet), only the series of tests for the first end tested of each pallet yielded unbiased data. This was especially true if the hardboard deck failed during the first test series, and this condition is readily shown in table 2 for sets of data corresponding to a panel thickness of ½ inch.

The thickness of the deck also proved to be the principal factor in pallet serviceability. In this regard, it was clear that a hardboard deck thickness of ¾ inch or more yielded pallet handling resistance behavior that was much superior to that of the lumber controls in all instances. The use of an impact panel enhanced this increase even more. Typical failure patterns, depending on deck thickness and impact loading method, are shown in figure 6. Shear failure of the hardboard deck occurred when the forks of a conventional forklift truck impacted and handled pallets with either ½- or ¾-inch decks as shown in figure 6A.[5] Similar pallets, with 1-inch-thick hardboard deck however, did not fail when impacted and handled by a forklift truck either operated conventionally or with an impact panel attached. If the forklift truck was equipped with an impact panel, a different type of failure eventually occurred, figure 6B. In this situation failure usually involved inadequate panel shear strength at the vertical load supports. The more extensive nature of such shear failure is illustrated typically by the top view of a pallet shown in figure 6C. Failure usually occurred near the boundaries for the supports for the load—i.e., where shear stresses were largest.

Bending Stiffness Tests

The slope of the load-deflection curve was taken to represent the stiffness in the elastic region for each pallet for a particular static loading cycle. Therefore, the load-deflection ratios were determined in the elastic region for three successive tests of each of five replicates. The resulting 15 ratios were averaged, and these values were used as a measure of the bending stiffness values for a particular pallet construction and loading arrangement. The results are shown in table 3.

One important point common to these basic data comparisons is the fundamental structural difference in bending stiffness

[5] Failure was judged arbitrarily to have occurred when a "fork bite" of 2 inches or more was produced from the leading edge.

Table 3.—*Bending stiffness test results*

FPL pallet designations	Pallet composition	Top deck thickness	Pallet stiffness (lbs/in.)					
			36-inch span			44-inch span		
			Range	Average	Hardboard pallets / Controls	Range	Average	Hardboard pallets / Controls
		In.						
C	Lumber (controls)	¾	7,220-9,560	8,440	—	427-510	468	—
H-1101	All hardboard	½	2,130-2,380	2,240	0.266	221-245	235	0.502
H-1102	All hardboard	¾	5,320-6,580	6,020	.713	550-667	611	1.31
H-1103	All Hardboard	1	11,900-12,500	12,200	1.440	1,370-1,610	1,480	3.16
OH-1101	Hardboard deck only	½	4,770-5,820	5,230	.620	222-258	238	.508
OH-1102	Hardboard deck only	¾	2,820-6,030	4,690	.556	510-633	592	1.27
OH-1103	Hardboard deck only	1	7,190-9,330	8,100	.960	1,260-1,520	1,400	3.00

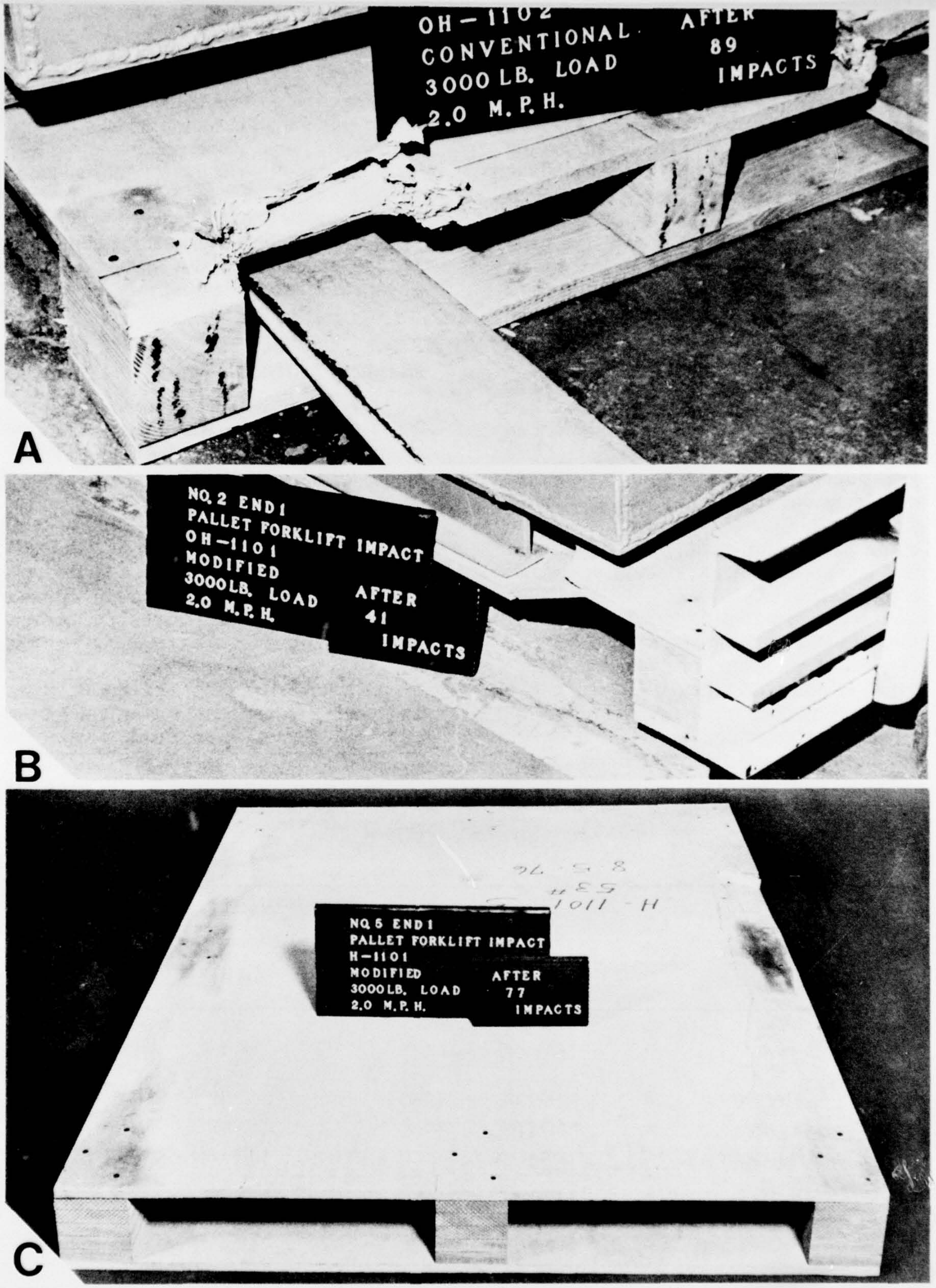

Figure 6.—Typical shear failure patterns of hardboard panels: A. along leading edge, B. along edges of one foot of the load, and C. showing a shear failure in a top deck.

(M 145 146-11)
(M 145 140-6)
(M 144 608)

related to loading orientation and span length for pallets of this type. Specifically, bending of pallets loaded at the quarter points of 44-inch spans essentially were resisted only by the bending resistance provided by the stringer boards of individual lumber control pallets and the hardboard top decks of the other pallets in the study (figs. 1 and 2). It is noteworthy that when the same pallets were rotated 90 degrees and tested again the average stiffness was markedly greater. For example, the stiffness of lumber control pallets when loaded with a 36-inch span was on the order of 18 times that of the 44-inch span, and the pallets made partially or entirely of hardboard components averaged from about 6 to 22 times the stiffness of the same pallets along the 44-inch span.

Some of the reasons for the difference in the stiffness of the controls were (a) a change in the span length between the supports from 44 to 36 inches; (b) involvement of all of the top deckboards, instead of only 3 stringer boards; and (c) the partial truss action of the pallet where bottom deckboards were used. Where hardboard decks were used, the principal causes for increased bending resistance were simply (a) shorter span and (b) the involvement of the bottom lateral deckboards.

Quantitatively, the average bending stiffness values of the red oak lumber control pallets for their 36- and 44-inch spans were 8,440 and 468 pounds per inch, respectively. In contrast essentially equal or greater average bending stiffness (12,200 and 8,100 pounds per inch for the 36-inch span and 1,480 and 1,400 pounds per inch for the 44-inch span) could be achieved by hardboard pallets having 1-inch-thick hardboard panels (table 3). This was true for both hardboard pallet designs, if bending was considered along both axes for any particular pallet design.

Diagonal Rigidity Tests

Lumber control pallets.—Each of the five red oak pallets racked considerably. Although damage caused by crushing of the components was slight, one consistent tendency observed was that the resistance of stringer boards to tension perpendicular to the grain was inadequate to withstand forces produced at the nails during drop testing. This usually caused the stringer boards to split. Because these boards were the only components resisting rotational distortion, the pallets then racked considerably (fig. 7). This tendency was measured by changes in the length of the diagonals between opposite corners. Expressed in terms of test data this generally amounted to an average decrease in the length of vertical diagonals, accompanied by an increase in the intermediate, essentially horizontal, diagonals.

The heads of nails in all pallets made with ½-inch-thick upper decks pulled through the hardboard during testing (fig. 8A). This usually occurred with similar pallets having ¾-inch-thick hardboard decks,

Table 4.—*A summary of results of diagonal distortion tests of pallets*

Pallet composition	Top deck thickness	Drops to failure		Average pallet distortion (%)[1]	
		Individual	Average	A-B, E-F	C-D, G-H
	In.				
Lumber (controls)	¾	______[2]		−2.94[3,4]	+2.75[3,4]
All hardboard	½	3,3,3,2,5	3.2	−.146	+.0104
All hardboard	¾	3,5,4,3,4	3.8	−.461	+.031
All hardboard	1	3,4,2,5,3	3.4	−.715	+.052
Hardboard deck,	½	3,3,3,2,3	2.8	−.220	+.063
lumber parts	¾	5,5,6,3,3	4.4	−.567	+.048
otherwise	1	5,5,6,8,5	5.8	−.619	+.105

[1] Based on change in length of diagonals because of drop testing.
[2] Although they were considerably racked after 12 drops, the pallets in this set remained intact.
[3] After 12 drops.
[4] "−" indicates a loss of length; "+", a gain.

but did not in pallets with 1-inch-thick hardboard panels (fig. 8B). Pallets with 1-inch-thick hardboard panels essentially remained rectangular, but failed by a combination of crushing of the hardboard panel corner, together with nail-pull from the block. Sometimes the blocks themselves split and failed. In general pallets with hardboard components failed in 3 to 8 impacts. As shown in table 4, they remained much more square until failure than the lumber controls, but they could withstand a good deal less total abuse.

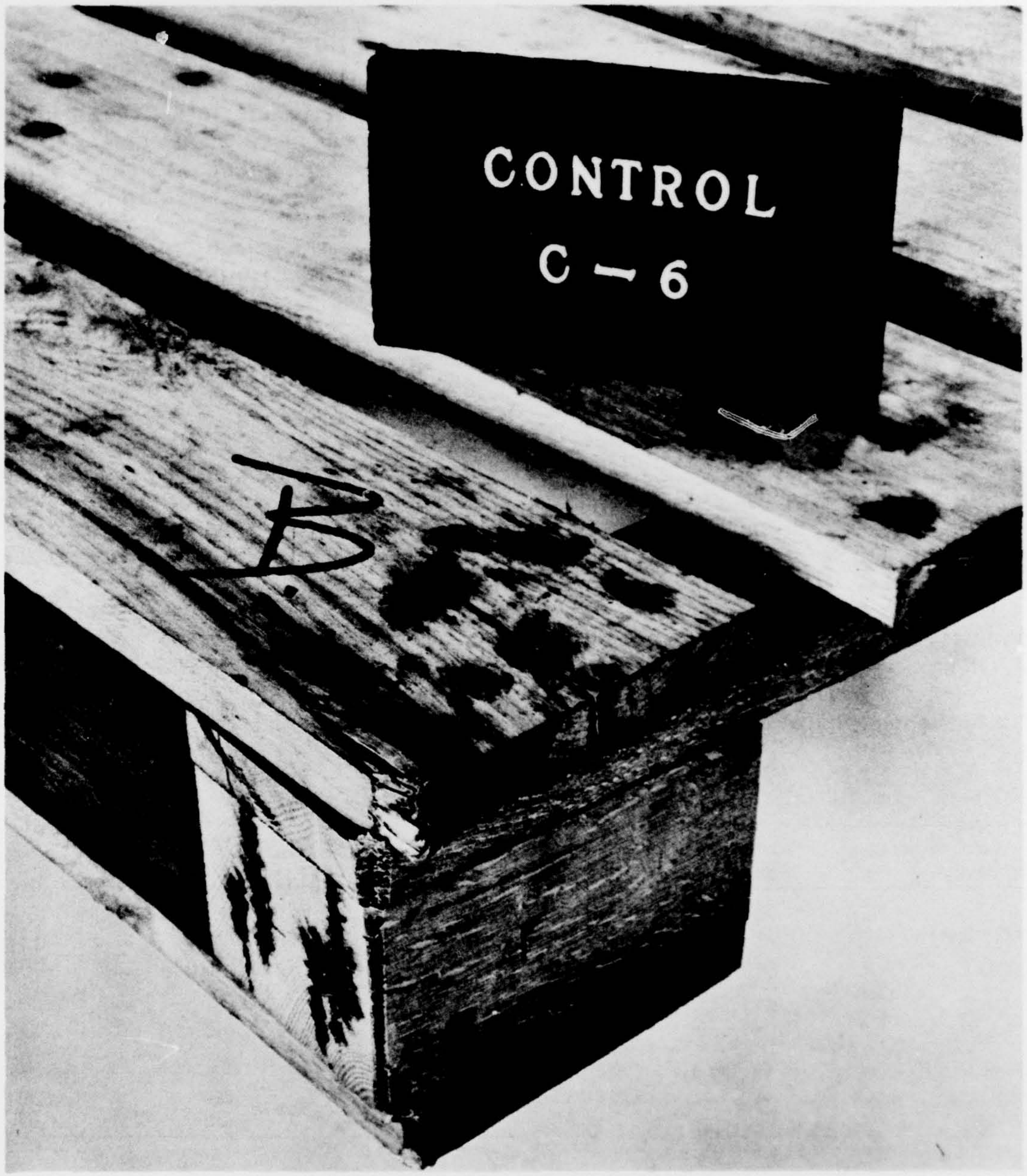

Figure 7.—Close up of racking behavior in an oak lumber pallet resulting from diagonal rigidity testing. (M 145 273-1)

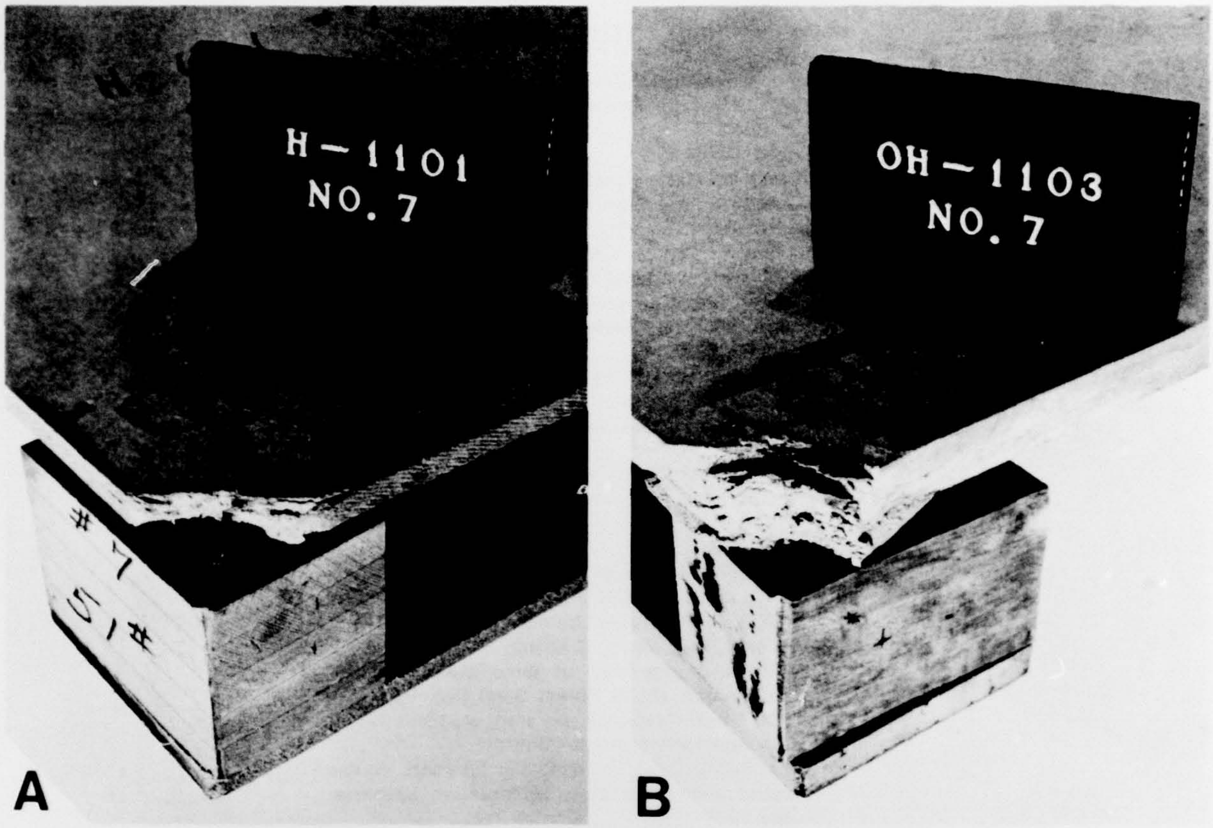

Figure 8.—Nailhead "pullthrough" behavior in hardboard pallets: A. through ½-inch thick hardboard, but B. not pulled through a 1-inch thick panel of similar hardboard during diagonal ridigity tests.
(M 145 274-5)
(M 145 273-3)

Conclusions

For the conditions investigated, urea bonded hardboard pallets with 1-inch-thick decks compared favorably with returnable red oak pallets of the same 9-block, 4-way entry design. However, further work is needed to determine the effects of greater moisture content, as might commonly be encountered under outdoor service conditions.

Whole or partial hardboard pallets of this type are more dimensionally stable, but less resistant to prolonged physical abuse, than comparable red oak pallets. Therefore, hardboard pallets might be more suitable than lumber pallets of the same design for indoor mechanized handling and palletizing operations.

Nine-block, 4-way entry pallets are much stiffer across their width, than along their length, because of a combination of a shorter span and the increased bending resistance offered by the pallet structure. This additional bending resistance is caused by involvement of the deckboards (if lumber pallets) and increased hardboard panel width (if a hardboard pallet).

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